A Dynamic Approach to Monitoring Particle Fallout in a Cleanroom Environment

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Introduction

- Particle fallout levels are commonly used for:
  - ± Estimating the effects of environmental exposure of sensitive surfaces
  - ± Development of contamination budgets

- Standard fallout measurement approaches require durations inversely proportional to the environmental cleanliness

- Cleanrooms are certified according to airborne particle count, and many cleanrooms are equipped with continuous monitoring

- The ability to estimate particle fallout based on airborne particle counts provides a more dynamic approach
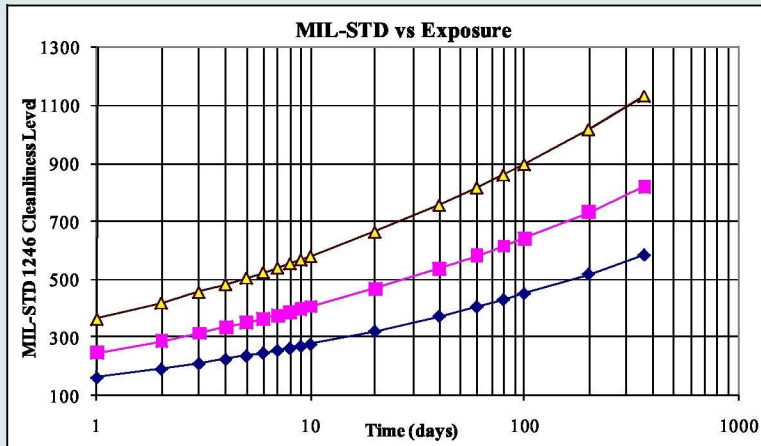
Assumptions

- Fallout rates are directly proportional to air quality
- Rates and quality directly reflect activity levels
- Once settled, particles remain
- Accumulation surfaces are horizontal

Simple Approach

Adapted from Hamburg, Proc. IES (1982)

- **Previous studies correlated cleanliness class to cleanliness level**
  - Cleanliness level is sensitive to particle distributions
    - MIL-STD 1246 (IEST-STD-CC-1246) cleanliness levels use -0.926 distribution slope
    - Airborne particle distribution follows a -0.28 slope
    - Distribution of particle fallout is -0.383
  - Results in non-linear relationship
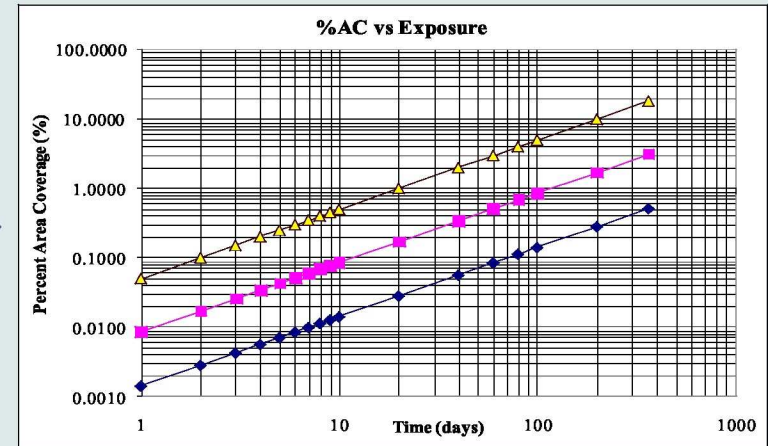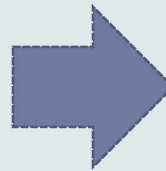
- Correlation to a normalized area coverage (e.g. PAC) provides a linear time relationship

- Simple substitution remains non-linear for cleanroom class

- # Airborne Particle Distribution (FED-STD-209)

$$n_x = Class * \left(\frac{0.5}{x} \right)^{2.2}$$

- # Effective Column Height (Stokes Coefficient)

$$\nu = \frac{2 * g * r^2 * (d_1 - d_2)}{9\mu}$$

Caveat: Limit column height by ceiling height and air exchanges

- # Obscuration Factor

$$OF = \left(\frac{x}{AR} \right)^2 * \left(\frac{\pi}{4} + AR - 1 \right)$$

Particle Size (microns)	Aspect Ratio (L:W)
1 - 69	$X^{0.1088}$
70 - 175	$X^{0.8804}/26.53$
176 - 346	$X^{2.589}/181500$
> 346	$X^{0.8964}/9.138$

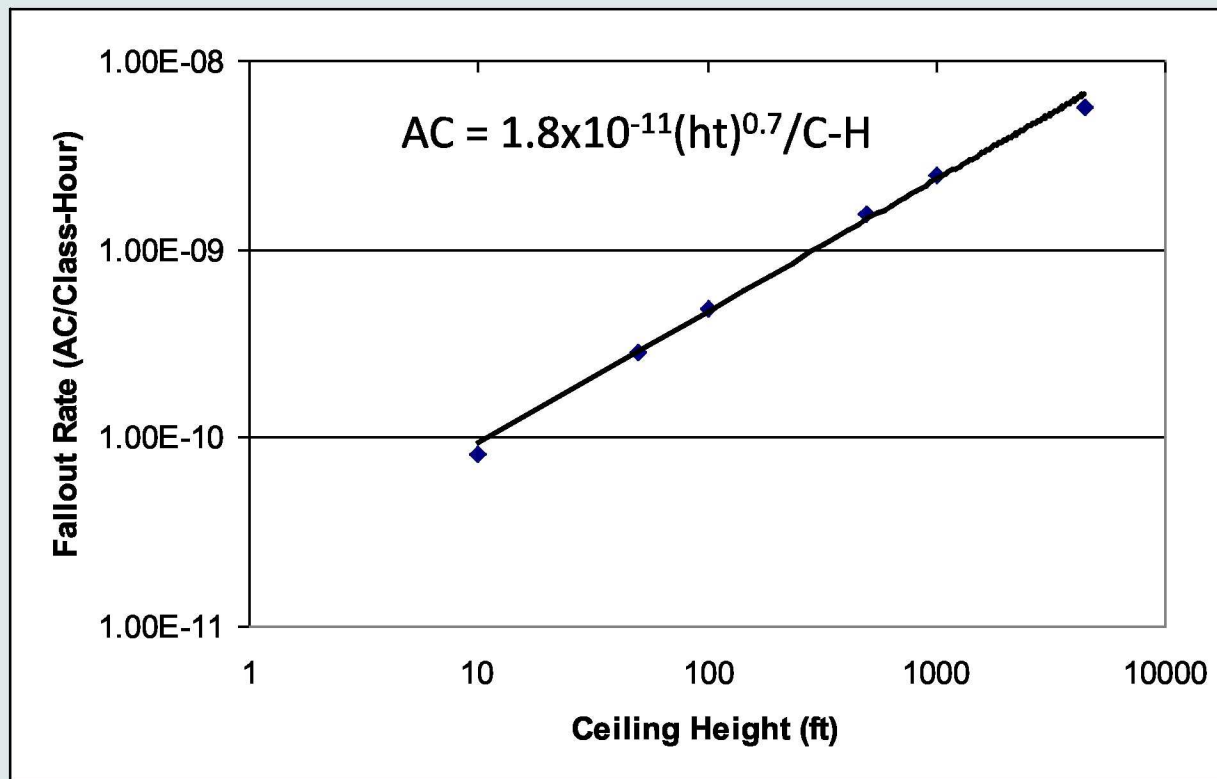*Adapted from Ma, Fong, and Lee, SPIE 1165 (1989)*

Putting It All Together

☐ Combination of distribution, column height, and obscuration factor provides a linear correlation of area coverage (AC) to cleanroom class and time (Class-Hours)

$$AC_x = \left[\frac{n_{x+1} - n_x}{Class} \right] * \left[v_{OF} * \frac{3600\, s}{hr} * \frac{ft}{30.48\, cm} \right] * \left[OF * \frac{1.076\, x10^{-11}\, ft^2}{\mu m^2} \right]$$

☐ A spreadsheet was used to determine the incremental contribution of AC for particles in 1 micron bins from 1 to 1000 microns

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$$AC = 1.8 \times 10^{-11}(ht)^{0.7}/C\text{-}H$$

Plot: Fallout Rate (AC/Class-Hour) vs Ceiling Height (ft)

For ISO 14644-1: $\quad n_x = 10^{Class} * \left(\dfrac{0.1}{x}\right)^{2.08}$ therefore $AC = 4.7 \times 10^{-14}(ht)^{0.81}/C\text{-}H$

- **Predictive:**
  - ± Assume a limit of 0.1 PAC in a facility with a 100 foot ceiling, this results in 2.2×10^6 Class-Hours
    - For a Class 10K facility: 220 hours
    - For one month duration: Class 3000
  - ± Assume covering off-shift (2/3 of each day)
    - For a Class 10K facility: 660 hours
    - For one month duration: Class 9000
- **Dynamic:**
  - ± Cleanroom environments are rarely static, but vary with activity level
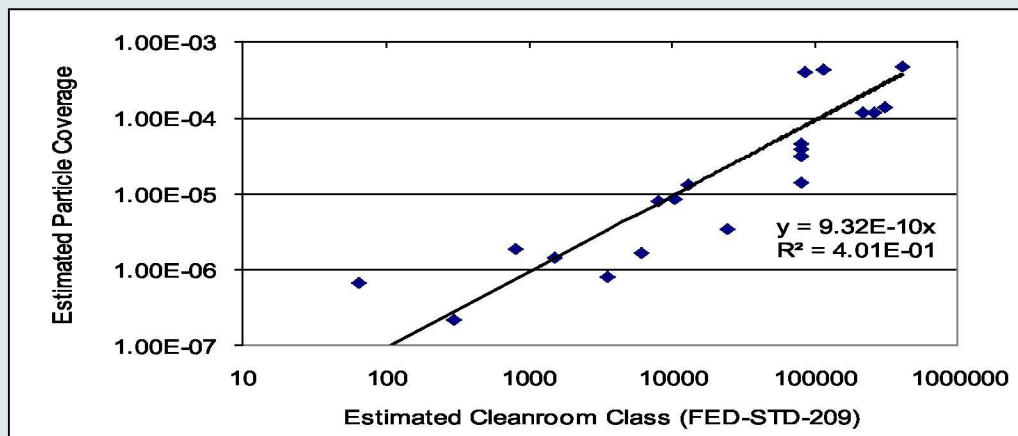 - ± Airborne particle counters can provide real-time data

Application
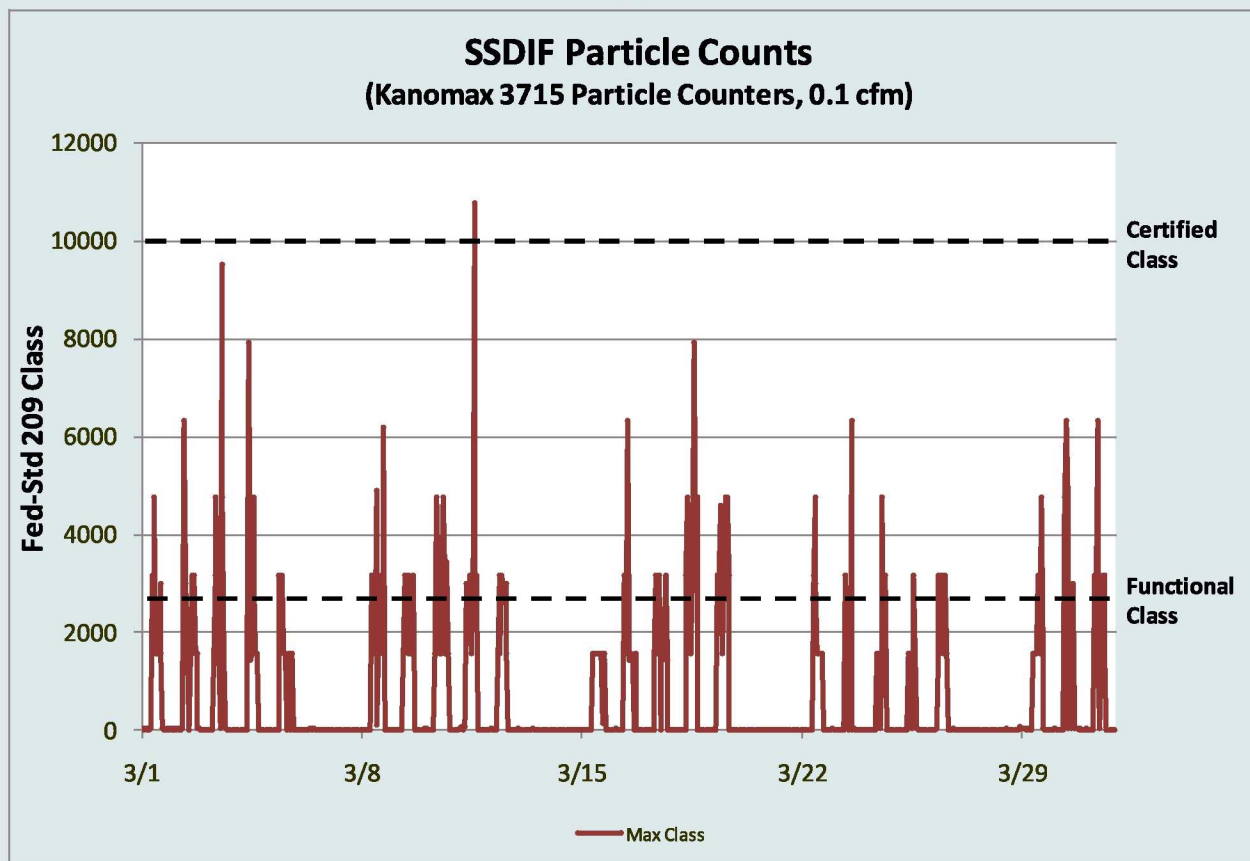
□ Hourly monitoring sums to 5.15×10^5 Class-Hours (>75% margin)

- # Ongoing monitoring at GSFC SSDIF
  - ## Estimated AC/C-H (100 ft ceiling): 4.5×10^{-10}
    - ### *{Estimated AC/C-H (43 exchanges/hr): 5.9×10^{-9}}*
  - ## Measured AC/C-H (5μm channel): $4.9(\pm 8.0) \times 10^{-10}$
    - ### *{Measured AC/C-H (0.5μm channel): $4.6(\pm 9.2) \times 10^{-9}$}*

- # Hamburg data: 9.3×10^{-10} AC/C-H

Chart: Estimated Particle Coverage vs. Estimated Cleanroom Class (FED-STD-209)

$y = 9.32E{-}10x$
$R^2 = 4.01E{-}01$

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